Chapter 7

Elemental Phosphorus Production

The elemental phosphorus industry consists of five facilities that, as of September 1989, were active and reported generating a mineral processing special waste: furnace slag. The data included in this chapter are discussed in additional detail in a technical background document in the supporting public docket for this report.

7.1 Industry Overview

Elemental phosphorus is used solely as a process input to produce a wide array of phosphorus chemicals. As a chemical manufacturing feedstock, it may be used directly, or oxidized and condensed to produce a high-purity "furnace-grade" phosphoric acid. Furnace-grade acid, in turn, is a feedstock for the production of sodium phosphates, such as sodium tripolyphosphate, a detergent builder, which historically has been a major product, and additional sodium phosphates (e.g., trisodium phosphate, sodium hexametaphosphate, tetrasodium pyrophosphate) which are used in cleaners, water treatment, and foods.[1] Furnace-grade acid is also used to manufacture calcium phosphates for animal feed, dentifrices, foods, and baking powders. Another grade of furnace process acid is technical-grade acid, which is primarily used to clean metals.

The five elemental phosphorus production facilities are located near phosphate rock reserves in areas where the cost of the large amount of energy required to operate the furnaces is relatively low. Facilities are found in central Tennessee, Montana, and Idaho (see Exhibit 7-1). The dates of initial operation for these facilities range from 1938 at Mt. Pleasant to 1952 at Soda Springs and Columbia. Except for the Silver Bow facility, all facilities report having modernized their production operations; the Soda Springs facility was upgraded in 1978 and the remaining three plants were modernized in 1988.[2] The reported 1988 elemental phosphorus production for the sector was 311,000 metric tons.[3] The sector-wide capacity utilization was, therefore, 91 percent during that year. Capacity data are presented in Exhibit

[1] Bureau of Mines, 1985 and 1987. Minerals Yearbook, 1987 Ed.; p. 677., and Mineral Facts and Problems, 1985 Ed.; p. 584.

[2] FMC Corp., Monsanto Co., Occidental Chemical Co., Stauffer Chemical Co. 1989. Company Responses to the "National Survey of Solid Wastes from Mineral Processing Facilities," U.S. EPA, 1989.

[3] Production statistics reported by three of the five facilities in the elemental phosphorous industry are confidential; because the three facilities are each owned by a different company, however, summary statistics for the sector can be reported without disclosing the facility-specific confidential data.

7-1.

Exhibit 7-1
Domestic Elemental Phosphorus Producers

Owner/Operator	Location	Capacity[(a)] (metric tons)[(b)]
FMC Corporation	Pocatello, ID	125,000
Monsanto Company	Soda Springs, ID	86,000
Occidental Chemical	Columbia, TN	52,000
Stauffer[(c)]	Mt. Pleasant, TN	41,000
Stauffer[(c)]	Silver Bow, MT	38,000

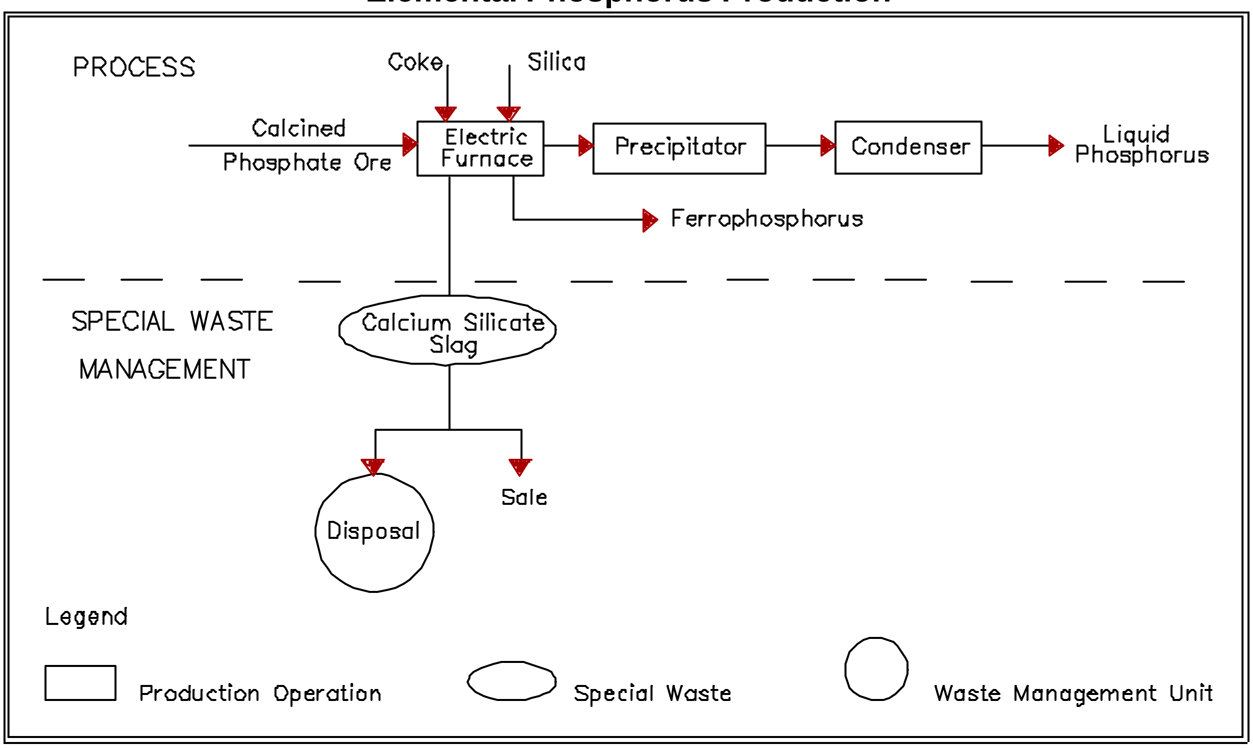
(a) SRI International, 1987. Directory of Chemical Producers--United States, 1987 Ed.; p. 869.
(b) Capacity data is on a P_4 basis.
(c) Rhone-Poulenc is the parent company.

Production of phosphate rock has steadily increased since 1986, when production fell off by more than 10 percent of the 1985 total. Most of the increase in production throughout the late 1980s however, was due to phosphate rock sold or used for wet process phosphoric acid production. The quantity of phosphate rock used in domestic elemental phosphorus production actually decreased from 3.2 million metric tons in 1986 to 3.0 million metric tons in 1987.[4]

In elemental phosphorus production, sized phosphate rock or sintered/agglomerated phosphate rock fines are charged to (introduced into) an electric arc furnace together with coke (a reducing agent) and silica (a flux), as shown in Exhibit 7-2.[5] The phosphorus contained in the rock is both liberated from the rock matrix and chemically reduced by the operation.

The process generates calcium silicate slag and ferrophosphorus, which are tapped from the bottom of the furnace in molten form, and carbon monoxide (CO) off-gases, which contain volatilized phosphorus. The gas is treated using a precipitator to remove impurities and the cleaned gas, still containing the gaseous phosphorus, is condensed using water to produce liquid elemental phosphorus. Following this treatment step, the off-gas is typically routed to the ore sintering furnaces for use as fuel, though it may also be treated and released. Treatment residuals (e.g., off-gas solids) are either recycled or disposed. The molten residues are either air- or water-cooled, (i.e., solidified). Ferrophosphorus is typically sold as a byproduct. The calcium silicate furnace slag, the special mineral processing waste, is generally accumulated in storage piles, then sold and/or disposed.

Exhibit 7-2
Elemental Phosphorus Production



[4] William F. Stowasser, U.S. Bureau of Mines, "Elemental Phosphorus," Minerals Yearbook, 1987 Ed., p. 679.

[5] Environmental Protection Agency, 1984. Evaluation of Waste Management for Phosphate Processing. Prepared by PEI Associates for U.S. EPA, Office of Research and Development, Cincinnati, OH; August, 1986.

7.2 Waste Characteristics, Generation, and Current Management Practices

The mineral processing special waste generated by elemental phosphorus production, furnace slag, is a solid material at ambient temperatures, although it usually is generated in a molten form. The slag is typically a light gray, heavy, extremely hard, and porous material. After cooling from its molten state, the slag is broken into cobble-to-boulder-size fragments. EPA analyses of this waste indicate that the solidified slag is a glass-like material that contains its constituents in a vitrified matrix. Elemental phosphorus slag is composed primarily of silicon and calcium and may contain radionuclides, including thorium-232, uranium-238, and decay products of these two radionuclides, such as radium-226.

Using available data on the composition of elemental phosphorus slag, EPA evaluated whether this waste exhibits any of the four hazardous waste characteristics: corrosivity, reactivity, ignitability, and extraction procedure (EP) toxicity. Based on available information, EPA does not believe that elemental phosphorus slag exhibits any of the four characteristics of hazardous waste. Data are available on the concentrations of all eight inorganics with EP toxicity regulatory levels and, with the exception of chromium, all of these constituents are present in EP leachate in concentrations that are at least two orders of magnitude below the regulatory level, that is, below drinking water levels. The maximum chromium concentration observed in the leachate is one order of magnitude below the EP toxicity regulatory level.

Furnace slag generation rate data were reported as non-confidential information by two of the five elemental phosphorus production facilities, Columbia and Silver Bow, who reported waste generation rates of approximately 354,000 and 272,000 metric tons, respectively. The aggregate industry-wide generation of slag by the five facilities was approximately 2.6 million metric tons in 1988, yielding a facility average of over 526,000 metric tons per year.[6] The sector-wide ratio of metric tons of slag to metric ton of elemental phosphorus was 8.4 in 1988; waste-to-product ratios ranged from 8.0 (average for the three facilities submitting confidential information) to 10.0 (at each of the other two facilities).

Two management practices predominate throughout the sector: 1) the sale of the slag for use as a construction material (e.g., as an aggregate) and 2) storage or disposal of the furnace slag in waste piles. Three facilities sold from 35 to 43 percent of the slag that they generated in 1988; the remainder of the slag was placed in "stockpiles." Of the two remaining facilities, the Columbia plant reported selling all of its slag, while the Silver Bow facility reported disposing all of its slag in a "slag pile." In 1988, the quantity of slag sent to disposal waste piles at the five facilities ranged from 0 to greater than 500,000 metric tons per facility, averaging 320,000 metric tons. As of 1989, stockpile areas at the five facilities ranged from 5 to 38 hectares (12 to 95 acres) per facility. The total quantity of slag accumulated in these piles in 1988 ranged from 1,500,000 to 21,000,000 metric tons per facility.[7]

With regard to environmental media protection controls, only the Soda Springs, Idaho, facility reports practicing dust suppression on its on-site waste piles, and none of the facilities report the use of liners or leachate collection systems to limit infiltration through the piles.

7.3 Potential and Documented Danger to Human Health and the Environment

In this section, EPA discusses two of the study factors required by §8002(p) of RCRA: (1) potential danger (i.e., risk) to human health and the environment; and (2) documented cases in which danger to human health and/or the environment has been proven. Overall conclusions about the hazards associated with elemental phosphorus slag are based on these two study factors and are presented at the end of this section.

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[6] Waste generation data that three facilities requested be confidential can be summed together and presented without revealing confidentiality, as the three facilities are owned by different companies.

[7] Stockpile area and accumulated quantity were not reported for two of the facilities.

7.3.1 Risks Associated With Elemental Phosphorus Slag

Any potential danger to human health and the environment posed by elemental phosphorus furnace slag depends on the presence of hazardous constituents in the slag and the potential for exposure to these constituents.

Constituents of Concern

EPA identified chemical constituents in furnace slag that may present a hazard by collecting data on the composition of the slag and evaluating the intrinsic hazard of the slag's constituents.

Data on Elemental Phosphorus Slag Composition

EPA's characterization of elemental phosphorus slag and any leachate that it might generate is based on data from four sources: (1) a 1989 sampling and analysis effort by EPA's Office of Solid Waste (OSW); (2) industry responses to a RCRA §3007 request in 1989; (3) sampling and analysis conducted by EPA's Office of Research and Development (ORD) in 1984; and (4) literature addressing the radiological properties and hazards of elemental phosphorus slag. These data provide information on the concentrations of 20 metals, 8 radionuclides, gross alpha and beta radiation, and a number of other inorganic constituents (e.g., phosphate, phosphorus, fluoride, chloride, sulfate, ammonia, and nitrate) in total and leach test analyses. Three of the five elemental phosphorus facilities are represented by these data: Rhone-Poulenc/Stauffer's facilities in Mt. Pleasant, Tennessee and in Silver Bow, Montana, and the FMC Corporation plant in Pocatello, Idaho.

Concentrations in total sample analyses of the slag are consistent for most constituents across all data sources and facilities. However, cadmium concentrations for the FMC facility in Pocatello are more than an order of magnitude higher than in any other analyses. Constituent concentrations obtained from leach test analyses of the slag are also generally consistent across the data sources, types of leach tests (i.e., EP, SPLP, and TCLP), and facilities.

Process for Identifying Constituents of Concern

As discussed in detail in Section 2.2.2, the Agency evaluated the waste composition data summarized above to determine if elemental phosphorus slag or its leachate contain any chemical or radiological constituents that could pose an intrinsic hazard, and to narrow the focus of the risk assessment. The Agency performed this evaluation by first comparing constituent concentrations to screening criteria and then by evaluating the environmental persistence and mobility of any constituents that are present in concentrations that exceed the screening criteria. These screening criteria were developed using assumed scenarios that are likely to overestimate the extent to which elemental phosphorus slag constituents are released to the environment and migrate to possible exposure points. As a result, this process eliminates from further consideration those constituents that clearly do not pose a risk.

The Agency used three categories of screening criteria that reflect the potential for hazards to human health, aquatic ecosystems, and water resources (see Exhibit 2-3). Given the conservative (i.e., overly protective) nature of these screening criteria, contaminant concentrations in excess of the criteria should not, in isolation, be interpreted as proof of hazard. Instead, exceedances of the criteria indicate the need to evaluate the potential hazards of the slag in greater detail.

Identified Constituents of Concern

Exhibits 7-3 and 7-4 present the results of the comparisons for elemental phosphorus slag total analyses and leach test analyses, respectively, to the screening criteria described above. These exhibits list all constituents for which sample concentrations exceed a screening criterion.

Of the 31 constituents analyzed in elemental phosphorus slag solids, only arsenic, cadmium, chromium, radium-226, and uranium-238 concentrations exceed a screening criterion (see Exhibit 7-3). All

Exhibit 7-3
Potential Constituents of Concern in Elemental Phosphorus Slag Solids[a]

Potential Constituents of Concern	No. of Times Constituent Detected/No. of Analyses for Constituent	Human Health Screening Criteria[b]	No. of Analyses Exceeding Criteria/ No. of Analyses for Constituent	No. of Facilities Exceeding Criteria/ No. of Facilities Analyzed for Constituent
Chromium	4 / 5	Inhalation*	4 / 5	2 / 2
Arsenic	3 / 5	Ingestion*	3 / 5	2 / 2
Radium-226	6 / 6	Radiation*(c)	4 / 6	2 / 3
Uranium-238	1 / 1	Inhalation* Radiation*(c)	1 / 1 1 / 1	1 / 1 1 / 1
Cadmium	3 / 5	Inhalation*	1 / 5	1 / 2

(a) Constituents listed in this table are present in at least one sample from at least one facility at a concentration that exceeds a relevant screening criterion. The conservative screening criteria used in this analysis are listed in Exhibit 2-3. Constituents that were not detected in a given sample were assumed not to be present in the sample.

(b) Human health screening criteria are based on exposure via incidental ingestion, inhalation, or all radiation pathways. Human health effects from ingestion and inhalation include both cancer risk and noncancer endpoints. Ingestion or inhalation screening criteria noted with an "*" are based on a $1x10^{-5}$ lifetime cancer risk; others are based on noncancer effects. "Radiation" entries are based on cancer risks from all radiation pathways.

(c) Includes direct radiation from contaminated land and inhalation of radon decay products.

of these constituents are metals or other inorganics that do not degrade in the environment. Chromium and radium-226 were detected in most of the samples analyzed (80 to 100 percent), and their concentrations in most analyses (approximately 70 to 80 percent) exceeded the screening criteria. Only cadmium and chromium were detected in concentrations that exceed the screening criteria by more than a factor of 10, however.

These exceedances of the screening criteria indicate the potential for the following types of impacts under the following conditions:

- Chromium, cadmium, and uranium-238 concentrations in the slag may pose a cancer risk of greater than $1x10^{-5}$ if dust from the slag piles is blown into the air in a concentration that equals the National Ambient Air Quality Standard for particulates and then is inhaled by nearby individuals.
- Arsenic concentrations in the slag could pose a cancer risk of more than $1x10^{-5}$ if the slag is incidentally ingested on a routine basis (which could occur if access to closed piles is not restricted or if the slag is used off-site in an unrestricted manner that could allow people to come into direct contact with slag).
- The concentrations of uranium-238, radium-226, and other members of the uranium-238 decay chain could pose a radiation hazard if the slag is allowed to be used in an unrestricted manner. For example, as discussed in more detail in the next section, direct radiation doses and doses from the inhalation of radon could be unacceptably high if the slag is used in construction material or if people were allowed to build homes on top of the slag.

Exhibit 7-4
Potential Constituents of Concern in Elemental Phosphorus Slag Leachate[a]

Potential Constituents of Concern	No. of Times Constituent Detected/No. of Analyses for Constituent	Screening Criteria[b]	No. of Analyses Exceeding Criteria/ No. of Analyses for Constituent	No. of Facilities Exceeding Criteria/ No. of Facilities Analyzed for Constituent
Phosphorus	3 / 3	Aquatic Ecological	3 / 3	2 / 2
Fluoride	3 / 3	Human Health Resource Damage	3 / 3 2 / 3	2 / 2 2 / 2
Arsenic	4 / 6	Human Health*	4 / 6	2 / 2
Manganese	4 / 5	Resource Damage	3 / 5	2 / 2
Aluminum	4 / 5	Aquatic Ecological	3 / 5	2 / 2
Phosphate	3 / 3	Aquatic Ecological	2 / 3	1 / 2
Chromium	1 / 6	Resource Damage	1 / 6	1 / 2
Zinc	3 / 5	Aquatic Ecological	1 / 5	1 / 2

(a) Constituents listed in this table are present in at least one sample from at least one facility at a concentration that exceeds a relevant screening criterion. The conservative screening criteria used in this analysis are listed in Exhibit 2-3. Constituents that were not detected in a given sample were assumed not to be present in the sample. The constituent concentrations used for this analysis are based on EP leach test results.

(b) Human health screening criteria are based on cancer risk or noncancer health effects. "Human health" screening criteria noted with an "*" are based on a $1x10^{-5}$ lifetime cancer risk; others are based on noncancer effects.

Based on a comparison of EP leach test concentrations of 29 constituents to the surface and ground-water pathway screening criteria (see Exhibit 7-4), only 8 constituents (i.e., arsenic, aluminum, chromium, manganese, fluoride, phosphorus, phosphate, and zinc) exceed the water-based criteria. All of these constituents are also metals or other inorganics that do not degrade in the environment. Chromium and zinc appear to be of less concern because they were detected less frequently in the samples analyzed (less than 60 percent of the samples), and their concentrations exceeded the screening criteria in less than 20 percent of the samples. Only manganese and phosphorus were measured in concentrations that exceed the screening criteria by more than a factor of 10. Despite these exceedances of the screening criteria, however, none of the samples contained any constituents in excess of the EP toxicity regulatory levels.

These exceedances of the screening criteria indicate the potential for the following types of impacts under the following conditions:

- If slag leachate is released to ground water and diluted by a factor of 10 or less during migration to a downgradient drinking water well, arsenic and fluoride concentrations could pose a health risk if ingested on a long-term basis without treatment. The diluted arsenic concentration could cause a cancer risk greater than $1x10^{-5}$.
- Concentrations of aluminum, phosphorus, phosphate, and zinc in slag leachate exceed the aquatic ecological screening criteria, suggesting that these contaminants could present a threat to aquatic ecological receptors if the leachate migrates (with 100-fold dilution or less) to surface waters.

- If slag leachate is released to ground water and diluted by a factor of 10 or less, the resulting concentrations of chromium, manganese, and fluoride could exceed the drinking water maximum contaminant level, potentially restricting future use of the ground water as a resource.

Although radionuclides in the slag solids appear to present a potential hazard, no radionuclides were detected at levels of concern in the slag leachate. Both radium-226 and gross beta contamination were analyzed in EP leach tests of the slag. The measured radium-226 concentrations ranged from 0.5 to 1.6 pCi/l, well below the maximum contaminant level of 5 pCi/l in drinking water. The measured gross beta concentrations ranged from 37 to 140 pCi/l, with an average of 83 pCi/l. While these values exceed the gross beta concentration recommended for drinking water,[8] 50 pCi/l, it is likely that the leachate concentration would be diluted by more than a factor of three if released to ground water. Therefore, any gross beta contamination in ground water caused by the release of the slag leachate is expected to be below the 50 pCi/l guideline.

These exceedances of the screening criteria, by themselves, do not demonstrate that the slag poses a significant risk, but rather indicate that the slag may present a hazard under a very conservative, hypothetical set of release, transport, and exposure conditions. To determine the potential for the slag to cause significant impacts, EPA proceeded to the next step of the risk assessment to analyze the actual conditions that exist at the facilities that generate and manage the waste.

Release, Transport, and Exposure Potential

This analysis considers the potential for direct radiation exposures associated with the off-site use of elemental phosphorus slag, as well as potential releases and exposures through the ground-water, surface water, and air pathways as the slag was generated and managed at the five elemental phosphorus production plants in 1988. For this analysis, the Agency did not assess risks associated with variations in waste management practices or potentially exposed populations in the future because of a lack of data on which to base projections of future conditions.

Direct Radiation Exposure Potential

As discussed in Section 7.5, elemental phosphorus slag has been widely used for many years for a variety of purposes. For example, in the Idaho and Montana area, the slag has been used as an aggregate in concrete and asphalt, railroad ballast, roadbed fill, and farm road gravel. It has also been used in the construction of homes, buildings, streets, sidewalks, parking lots, school playgrounds, and other structures.

Many of these uses can cause increased radiation exposure to people living or working near the slag-bearing materials. Exposure is principally from direct gamma radiation emitted from radionuclides contained in the slag, but there is also a possibility for radiation exposure through the inhalation of radon decay products that may accumulate in the indoor air of structures built over or with the slag. Inhalation of slag dust originating from road traffic is also a possible exposure pathway.[9]

A recent EPA study[10] provides estimates of the direct radiation exposures and risks caused by the off-site use of elemental phosphorus slag in Pocatello and Soda Springs, Idaho. Exposure to outdoor sources (e.g., slag used in street paving) was estimated to be the greatest contributor to radiation doses in Pocatello. Average gamma-ray doses in Pocatello caused by the slag were estimated to be 14 millirem/year, posing a lifetime fatal cancer risk of 4×10^{-4}. Calculated maximum doses and risks in Pocatello were roughly a factor of 10 higher. In Soda Springs, exposure to direct radiation within the home, caused by the use of slag in home foundations, was determined to be the greatest contributor

[8] No maximum contaminant level for gross beta contamination has been established, but compliance with 40 CFR 141.16 may be assumed if gross beta concentrations are less than 50 pCi/l.

[9] Conference of Radiation Control Program Directors, 1981. Natural Radioactivity Contamination Problems, Report No. 2, Report of the Committee, August 1981, p. 28.

[10] Environmental Protection Agency Study, 1990. Idaho Radionuclide Study. Office of Research and Development, Las Vegas Facility, Las Vegas, NV, April 1990.

to radiation doses. Average gamma-ray doses in Soda Springs caused by the slag were estimated to be 52 millirem/year, posing a lifetime risk of fatal cancer of 1.4×10^{-3}. Doses and cancer risks to the maximally exposed individual in Soda Springs were 205 millirem/year and 6×10^{-3}, respectively. While these risk estimates are presented in the EPA study, the Agency notes that the actual risks in Pocatello and Soda Springs could be roughly a factor of two higher.[11] For comparison, EPA's environmental radiation standards in 40 CFR 190 require operations in the uranium fuel cycle (including nuclear reactor operations) to keep radiation doses to members of the general public to less than 25 millirem/year.

While the study in Pocatello and Soda Springs did not detect a radon problem caused by the elemental phosphorus slag, elevated concentrations of radon in indoor air caused by the slag have been detected in other areas of the country. For example, indoor radon measurements conducted in 1,771 homes located in Butte, Montana revealed that 243 homes (14 percent) had indoor radon daughter concentrations above 0.02 working level,[12] attributable to elemental phosphorus slag.[13] For comparison, EPA's cleanup standards in 40 CFR 192 for soils near inactive uranium mill tailings sites limit the concentration of indoor radon decay products to 0.02 working level.

Ground-Water Release, Transport, and Exposure Potential

EPA's waste characterization data discussed above indicate that a number of constituents may leach from the elemental phosphorus slag at concentrations above the screening criteria. Considering only those contaminants that are mobile in ground water (given the existing slag management practices and neutral pH conditions that are expected), elemental phosphorus slag stockpiles could release arsenic, chromium, fluoride, phosphorus, and phosphate at concentrations that exceed the screening criteria. Manganese, aluminum, and zinc in the slag leachate are expected to be relatively immobile in ground water and should not be readily transported if released. Factors that influence the potential for these contaminants to be released and cause impacts through the ground-water pathway are summarized in Exhibit 7-5.

None of the elemental phosphorus plants report the use of engineered controls (e.g., liners, leachate collection systems) to limit infiltration through the piles.[14] Consequently, EPA evaluated the hydrogeologic setting of the plants to determine the potential for ground-water contamination from infiltration of precipitation through the slag piles.

- Compared to the other elemental phosphorus plants, both the Mt. Pleasant and Columbia plants are located in areas with relatively high to moderate potential for contaminants to migrate into ground water (i.e., net recharge is relatively high [25 cm/yr], but the aquifer is moderately deep [15 m]); both are in central Tennessee. Although drinking water wells could exist at private residences located 700 and 200 meters downgradient of the Mt. Pleasant and Columbia plants, respectively, the concentration of any released contaminants at these potential exposure points is likely to be below levels of concern (considering the generally low concentrations measured in the leachate).

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[11] In December 1989, the National Research Council published its Biological Effects of Ionizing Radiation or BEIR 5 Report that offers new risk estimates from radiation exposure. These new risk factors are about twice the risk factors used in the Pocatello and Soda Springs study.

[12] A "working level" is any combination of short-lived radon decay products in one liter of air that will result in the emission of alpha particles with a total energy of 130 billion electron-volts.

[13] Environmental Protection Agency, 1983. Evaluation of Radon Sources and Phosphate Slag in Butte, Montana. EPA 520/6-83-026, Washington, DC, June, 1983.

[14] The Silver Bow and Columbia plants did not provide data on their stockpiles. In the absence of better data, EPA has assumed that the piles at these facilities are not equipped with ground-water release controls.

Exhibit 7-5
Summary of Release, Transport, and Exposure Potential for Elemental Phosphorus Slag

Facility	Release, Transport, and Exposure Potential for Elemental Phosphorus Slag	Proximity to Sensitive Environments
SILVER BOW	**<u>Ground Water</u>:** Low net recharge (2.5 cm/yr) and large depth to aquifer (27 m) restrict ground-water contamination potential; potential drinking water exposure at residences within 800 m downgradient. **<u>Surface Water</u>:** Releases limited by low annual precipitation (34 cm/yr), gentle topographic slope (< 2%), and large distance (520m) to nearest stream; no known uses of stream, but its small size (5.2 mgd) indicates little assimilation capacity and, therefore, possible resource damage and aquatic ecological risks. **<u>Air</u>:** Insufficient data on pile size and dust suppression practices to support conclusion on release potential (although, facility monitoring of air quality has not detected any exceedance of air quality standards); average wind speeds up to 5.1 m/s and moderate number of wet days (78 days/year) could lead to airborne dust; potential exposures at residences as close as 640 m from the facility; population within 1, 5, and 50 miles of the facility is 79; 608; and 73,154, respectively.	No sensitive environments within 1.6 km
SODA SPRINGS	**<u>Ground Water</u>:** Releases from the slag pile may be limited by in-situ clay beneath the pile, low net recharge (5 cm/yr), and large depth to usable aquifer (27 m), but ground-water contamination that may be attributable to slag management has occurred at the site; potential drinking water exposures could occur at residences located only 60 m downgradient of the facility. **<u>Surface Water</u>:** Releases limited by stormwater runon/runoff controls and low annual precipitation (35 cm/yr); a river (420 mgd) is located 340 m from the facility, but it is not a source of drinking water near the facility, although it does provide irrigation water 270 m downstream of the facility. **<u>Air</u>:** Dust suppression used, but resident complaints indicate it may not be effective; average wind speeds up to 3.5 m/s and moderate number of wet days may (74 days/year) limit airborne dust; potential inhalation exposures at residences located adjacent to the facility boundary, and food chain exposures through deposition of particulate matter on agricultural fields in the vicinity of the facility; population within 1, 5, and 50 miles of the facility is 369; 4,580; and 100,598, respectively.	Wetland within 1.6 km

Exhibit 7-5 (cont'd)
Summary of Release, Transport, and Exposure Potential for Elemental Phosphorus Slag

Facility	Release, Transport, and Exposure Potential for Elemental Phosphorus Slag	Proximity to Sensitive Environments
POCATELLO	**<u>Ground Water</u>:** Ground-water monitoring indicates contamination possibly attributable to slag management; pile is unlined, but leaching of slag contaminants to useable ground water may be limited by low net recharge (1.2 cm/yr), great depth to aquifer (61 m), and presence of an intermediate, perched water table above the useable aquifer; potential drinking water exposures at residences located 300 m downgradient of the facility. **<u>Surface Water</u>:** Releases limited by the large distance to the Portneuf River (1400 m) and low annual precipitation (29 cm/yr); the nearest stream (with a flow of 160 mgd) is used for fish hatching 2.4 km downstream from the facility. **<u>Air</u>:** Potential releases are not controlled by dust suppression but the number of wet days that could suppress dust is moderately high (91 days/year); average wind speeds up to 6 m/s could lead to windblown dust, and air quality monitoring at the facility has indicated past exceedance of the air quality standard for respirable particulate matter; potential inhalation exposures at residences as close as 240 m from the facility, and food chain exposures through deposition of particulate matter on agricultural fields in the vicinity of the facility; population within 1 mile is sparse (31 people) but population within 5 and 50 miles is 35,869 and 166,100, respectively.	No sensitive environments within 1.6 km
MT. PLEASANT	**<u>Ground Water</u>:** Pile underlain by in-situ clay, but high net recharge (25 cm/yr) and moderately deep aquifer (15 m) indicate high to moderate potential for release; potential drinking water exposures at residence located 700 m downgradient from facility. **<u>Surface Water</u>:** Although stormwater runon/runoff controls are employed, release potential is high because of high annual precipitation (130 cm/yr), moderate topographic slope (up to 6 percent), and short distance (120 m) to a nearby stream; no known uses of the stream (which has a flow of 1.5 mgd), but its small size indicates potential resource damage and ecological impacts resulting from small assimilation capacity. **<u>Air</u>:** Potential releases are not controlled by dust suppression, but may be limited by the relatively small size of the piles (3 to 9 acres) and the large number of wet days per year (105); average wind speeds up to 4.6 m/s could, nevertheless, lead to windblown dust; potential inhalation exposures at residences as close as 700 m from the facility; population within 1, 50, and 50 miles is 145; 8,435; and 479,893, respectively.	No sensitive environments within 1.6 km

Exhibit 7-5 (cont'd)
Summary of Release, Transport, and Exposure Potential for Elemental Phosphorus Slag

Facility	Release, Transport, and Exposure Potential for Elemental Phosphorus Slag	Proximity to Sensitive Environments
COLUMBIA	**Ground Water:** No data on management controls at the pile, but potential releases indicated by high net recharge (25 cm/yr) and moderately deep aquifer (15 m below land surface); potential drinking water exposures at residence located 210 m downgradient of the facility. **Surface Water:** No data on management controls at the pile, but potential releases indicated by high amount of annual precipitation (130 cm/yr), short distance to a nearby river (110 m), and moderate topographic slope (up to 6%); potential drinking water exposure from a public water supply intake located 12 km downstream. **Air**: No data on management controls at the pile, but releases may be limited by the large number of wet days per year (105); average wind speeds up to 4.6 m/s could, nevertheless, lead to wind blown dust; high inhalation exposure potential at a residence located 60 m from the facility, and potential food chain exposures through deposition of particulate matter on agricultural fields in the vicinity of the facility; population within 1, 5, and 50 miles is 418; 40,312; and 935,013, respectively.	Located in area of karst terrain; no other sensitive environments within 1.6 km

- The potential for ground-water contamination caused by the elemental phosphorus slag stockpiled at the Soda Springs (ID) plant appears to be relatively low based on the low net recharge (5 cm/yr) and the large depth to the aquifer (24 m). However, if contaminants reach the aquifer beneath this plant, they may pose human health risks (via drinking water) at a residence located less than 100 meters downgradient.
- The potential for slag at the Pocatello and Silver Bow plants to cause ground-water contamination appears lower because of even smaller net recharge (1.2 to 2.5 cm/year) and larger depths to useable aquifers (27 to 61 meters). Releases to the useable aquifer beneath the Pocatello plant are further limited by the presence of an intermediate, perched aquifer above the useable aquifer. If releases were to occur, exposures at these facilities may occur 300 meters downgradient of the Pocatello plant and 880 meters from the Silver Bow plant. Given the generally low concentrations of contaminants measured in the slag leachate, however, the concentrations at these distance exposure points are likely to be below levels of concern.

Ground-water monitoring results from Soda Springs, Pocatello, and Silver Bow show that releases to ground water have occurred although the extent to which the slag piles have contributed to this contamination is still under investigation. These facilities report that drinking water standards for fluoride, chloride, manganese, sulfate, cadmium, and selenium have been exceeded in downgradient monitoring wells. Except for chloride and selenium, these constituents have been detected in leach test analyses of elemental phosphorus slag. Therefore, although the facilities state that ground-water contamination cannot definitely be attributed to the stockpiles,[15] EPA's waste characterization data suggest that the slag piles may have contributed to observed ground-water contamination at these facilities.

Surface Water Release, Transport, and Exposure Potential

Constituents of potential concern in elemental phosphorus slag could, in theory, enter surface waters by migration of slag leachate through ground water that discharges to surface water, or by direct overland (storm water) run-off of dissolved or suspended slag materials. As discussed above, the following constituents leach from the slag at levels that exceed the screening criteria: arsenic, chromium, manganese, aluminum, fluoride, phosphorus, and phosphate. Other constituents present in the slag, such as cadmium, could also present surface water threats if slag particles reach surface waters.

The potential for overland release of slag particles to surface waters is limited considerably by the generally large size of the slag fragments. A small fraction of the slag material, however, may consist of fragments that are small enough to be erodible (i.e., approximately 0.01 cm in diameter or smaller). Because the stockpiles have relatively steep slopes (from 13 to 27 percent), erosion from the piles could lead to the overland flow of small slag particles or dissolved slag contaminants to nearby surface waters. At the Mt. Pleasant and Soda Springs plants, however, potential storm water run-off from the piles would be limited by the run-off controls reported by these two facilities.

Three of the four elemental phosphorus facilities providing data report that they monitor water quality in streams in the vicinity of the plant. Pocatello and Soda Springs report that ambient surface water concentrations downstream of their plants have exceeded drinking water standards or ambient water quality criteria (AWQC). Constituents detected in exceedance of standards or criteria include sulfate, cadmium, chloride, selenium, and manganese. All of these constituents have been detected in the slag. Therefore, the slag stockpiles cannot be ruled out as a possible source of this contamination based on EPA's waste characterization data, although site-specific factors (discussed below) indicate that the slag piles are likely to be only minor contributors to the contamination.

EPA's assessment of the potential for surface water releases and exposures at each facility depends on the use of controls to limit storm water run-off, hydrologic characteristics of the plant locations, the proximity of the plants to nearby streams, and the uses of these streams.

- The Columbia plant has moderate potential for releases of overland flow and ground-water seepage to surface water because it receives a relatively large amount of precipitation (i.e., 130 cm/year), which can transport contaminants by recharge to ground water or overland flow, and is located only 110 meters from Rutherford Creek.[16] However, the surface water damage potential is low, and not moderate or high, because the nearby creek has a large capacity to assimilate contaminant inflows (i.e., its annual average flow is 680 mgd).
- The Mt. Pleasant plant also has a moderate surface water release potential. Although this plant is located 120 meters from a small stream (Big Bigby Creek) with a flow of 1.5 mgd, overland releases of storm water run-off from its slag pile would be limited by run-off controls. As discussed above, this facility has a relatively high ground-water release potential. Therefore, seepage of contaminated ground water from the pile to the nearby stream may present aquatic ecological risks in the stream and/or restrict uses of this surface water resource (if it is large enough to be used). No health risks to existing human populations are expected because there are no intakes for drinking water supplies within 24 km (15 miles) of the plant.
- Slag piles at the western plants (Silver Bow, Pocatello, and Soda Springs) have relatively low surface water contamination potential because of large distances to nearby surface waters (i.e., 340 to 1,400 meters), low levels of precipitation (i.e., 29 to 35 cm/year), and relatively low ground-

[15] For example, Monsanto attributes ground-water contamination at the Soda Springs facility to the pre-1984 use of unlined ponds for managing process wastewater. Refer to the case study findings later in this section for a discussion of the ground-water contamination at the Pocatello plant.

[16] Occidental did not provide information on the use of run-on/run-off controls at the slag pile, therefore, EPA assumes that releases from this unit are not limited by engineered controls.

water release potential. The release potential at the Soda Springs plant is further limited by storm water run-off controls employed at the slag pile. If releases to these surface waters did occur, the potential for resource damage and aquatic ecological risks is greatest at the Silver Bow plant because the Silver Bow Creek has a small assimilative capacity (less than 5.2 mgd). If releases from the Pocatello plant reach the Portneuf River and are not sufficiently diluted, they could endanger aquatic life in the river, harm current use of the river as a fish hatchery, and restrict potential future uses of the river. Releases from slag piles at the Soda Springs plant could jeopardize consumptive uses of Little Spring Creek and Bear River (such as the current use for irrigation) and endanger the streams' aquatic life, if contaminants are not sufficiently diluted by the water's flow.

In summary, although surface water releases may be somewhat limited by the physical form of the slag and the use of storm water run-off controls at two facilities (Mt. Pleasant and Soda Springs), surface water releases of slag contaminants may occur by the seepage of leachate to ground water that discharges to surface water or by the overland flow of small fragments of slag. At the two facilities located in Tennessee (Mt. Pleasant and Columbia), surface water releases are more likely than at the facilities in Idaho and Montana (Pocatello, Soda Springs, and Silver Bow) because of the greater amount of precipitation (which leads to overland flow and ground-water discharge) and their close proximity to streams. Only slag at the Columbia plant poses a potential human health threat via the surface water pathway at present, and even this threat is very minor considering the large assimilative capacity of Rutherford Creek. The other facilities conceivably may pose aquatic ecological threats and/or restrict current and potential future uses of the streams, if contaminants entering these waters are not sufficiently diluted.

Air Release, Transport, and Exposure Potential

Because all of the constituents of concern in elemental phosphorus slag are nonvolatile, slag contaminants can be released to air only in the form of dust particles. As discussed above, uranium-238, cadmium, and chromium are present in the slag in concentrations that exceed the inhalation screening criteria. EPA's Office of Air and Radiation recently promulgated regulations governing the airborne emissions of radionuclides from elemental phosphorus plants (54 FR 51654, December 15, 1989). However, these standards apply only to airborne releases of radionuclides from calciners and nodulizing kilns, not to slag management units or operations.

Factors that affect the potential for airborne releases -- by either wind erosion or vehicular traffic disturbance -- include the particle size and moisture content of the slag, the area of the stockpiles, wind speeds, and the use of dust suppression methods.

Release of elemental phosphorus slag particles to the air is limited in part by the large particle size and glassy form of the slag. In general, particles that are $\leq$ 100 micrometers (µm) in diameter are wind suspendable and transportable. Within this range, however, only particles that are $\leq$ 30 µm in diameter can be transported for considerable distances downwind, and only particles that are $\leq$ 10 µm in diameter are respirable. The slag generally consists of particles larger than 100 µm in diameter (i.e., the maximum particle size that is suspendable and transportable), and therefore, the majority of the slag is not suspendable, transportable, or respirable. It is likely that only a small fraction of the slag will be weathered and aged into smaller particles that can be suspended in air, and after the small, near-surface particles are depleted, airborne emissions would be expected to decline to low levels. Nevertheless, considering the large exposed surface area of the slag stockpiles and concerns about dusting that have been expressed by EPA Regional personnel and local residents, the Agency acknowledges that large quantities of dust from elemental phosporous slag piles may be blown into the air during high winds.

Other, site-specific factors that influence the potential for dusting and subsequent exposures are described below:

- Potential dust releases from the Columbia plant may be limited by the large number (105 days/year) of days with precipitation. However, this plant has a relatively high air pathway exposure potential because the nearest residence is located only 46 meters away from the plant, and the population in the vicinity of the facility is relatively dense (i.e., population within 1.6, 8, and 80 km (1, 5, and 50 miles) is 418; 40,312; and 935,013 people, respectively).

- At the Pocatello plant, high dust suspension potential is indicated by past exceedances of the air quality standard for respirable particulate matter and high wind speeds (an average of up to 6 m/s). The source of this dust is not specified in the available data. The number of days with precipitation that could suppress dust is moderate (91 days/year). Air pathway exposures could occur at residences located 240 meters from this plant. The population within 1.6 km (one mile) of the facility is relatively sparse (31 people), but the population within 8 and 80 km (5 and 50 miles) is 35,900 and 166,100 people, respectively.

- Although dust suppression is practiced to control airborne releases from the Soda Springs slag pile, complaints about windblown dust from the stack indicate that this control may not be effective. Potential exposures could occur at a residence located directly adjacent to the facility boundary near the stack, and the population within 1.6, 8, and 80 km (1, 5, and 50 miles) of the facility is relatively dense (i.e., 369; 4,600; and 100,600 people, respectively).

- Silver Bow and Mt. Pleasant have relatively low air pathway release and exposure potential because of more moderate typical winds and the greater distance to nearby residences (640 to 805 meters). The potential for release may be comparatively greater at the Silver Bow facility because of the smaller number of days with precipitation that could suppress dust (78 days/year), and the higher average wind speeds (5.1 m/s). The potential for exposure, on the other hand, is greater at the Mt. Pleasant facility because of the dense population around the facility (population within 1.6, 8, and 80 km (1, 5, and 50 miles) is 145; 8,400; and 479,900 people, respectively).

Three of the facilities -- Soda Springs, Pocatello, and Columbia -- are located in areas with significant agricultural land use. In addition to potential inhalation risks, airborne releases of slag contaminants at these facilities could enter the human food chain through the deposition of suspended slag particles onto crops. Based on these findings, EPA acknowledges the need for further study and possible control of windblown dust from elemental phosphorus slag piles, especially at the Soda Springs, Pocatello, and Columbia facilities, both during the operating life of the piles and after closure.

Proximity to Sensitive Environments

As summarized in Exhibit 7-5, only the Soda Springs and Columbia plants are located in environments that are vulnerable to contaminant releases or environments with high resource value that may warrant special consideration.

- The Soda Springs facility is located within one mile of a wetland area (defined here to include swamps, marshes, bogs, and other similar areas). Wetlands are commonly entitled to special protection because they provide habitat for many forms of wildlife, purify natural waters, provide flood and storm damage protection, and afford a number of other benefits. Although the potential for ground-water and surface water releases from the slag pile at this facility is low, any such releases could adversely affect the function and value of this wetland area.

- The Columbia facility is located in an area of karst terrain (i.e., irregular topography characterized by solution features in soluble rock such as limestone). Releases to ground water in karst terrain can pose ground-water and surface water health risks and ecological risks because of the limited dilution potential of the conduit flow that is characteristic of ground-water movement in such areas (i.e., solution cavities that may exist in the bedrock at this site could permit any ground-water contamination originating from the slag pile to migrate in a largely unattenuated and undiluted fashion).

Risk Modeling

Based upon the evaluation of intrinsic hazard, the descriptive analysis of factors that influence risk presented above, and upon a comprehensive review of information on documented damage cases (presented in the next section), EPA has concluded that the ground-water and surface water risks posed by elemental phosphorus furnace slag are relatively low when the slag is managed on-site according to current practice. However, windblown dust at three facilities may pose a moderate risk via the inhalation and ingestion pathways. This overall conclusion is supported by the generally low to moderate risk estimates predicted by the Agency's modeling of other mineral processing wastes that appear to pose a substantially greater risk when managed in on-site stockpiles. Therefore, the Agency has not conducted a quantitative risk modeling exercise to examine the hazards of on-site slag management in greater detail. The Agency recognizes that the radiation risks associated with the off-site use of elemental phosphorus slag are high. EPA did not attempt to model these risks, however, because the recently completed study in Pocatello and Soda Springs provides definitive risk estimates based on actual field observations.

7.3.2 Damage Cases

State and EPA regional files were reviewed in an effort to document the environmental performance of slag waste management practices at the five elemental phosphorus facilities. The file review process was combined with interviews with state and EPA regional regulatory staff to develop a complete and accurate assessment of the extent to which slag has resulted in cases of documented danger to human health or the environment.

These sources did not reveal any sites with documented environmental damage that was clearly the result of management practices at units containing elemental phosphorus slag. However, concentrations of some heavy metals in ground water in excess of primary drinking water standards were documented, along with abandonment of an off-site drinking water well due to heavy metal contamination at the FMC facility in Pocatello.[17] The information reviewed indicates that unlined waste ponds appeared to be the source of the contamination at this facility. These unlined ponds, which have been replaced by lined ponds, contained a variety of wastewaters, including "phossy water, precipitator dust slurry, calciner scrubber water, slag cooling water, and general site run-off." None of these waste management units are known to contain slag; however, the slag cooling water pond, and possibly the "rainwater pond" as well, are related to slag management. Sampling of the ponds during a Superfund Site Investigation indicated that concentrations of some constituents in the slag cooling water pond were more than 100 times the primary drinking water standard.[18,19]

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[17] Ground-water contamination in the area of the facility and the adjacent J. R. Simplot phosphoric acid plant has led to the area being proposed for the Superfund National Priority List (see Eastern Michaud Flats Contamination).

[18] Ecology & Environment, 1988. Site Inspection Report for FMC/Simplot, Pocatello, Idaho. TDD F10-8702-09110. April, 1988.

[19] Ecology & Environment, 1988. Special Study Waste Analysis for Eastern Michaud Flats Groundwater Contamination. November, 1988.

7.3.3 Findings Concerning the Hazards of Elemental Phosphorus Slag

Based upon the detailed examination of the intrinsic hazards of elemental phosphorus slag, the management practices that are applied to this waste, the environmental settings in which the generators of the material are situated, and the documented environmental damages that have been described above, EPA concludes that these wastes pose a low to moderate risk to human health and the environment as currently managed on-site, but a high risk when used off-site in construction due to the radioactivity of the material.

Available data on the composition of elemental phosphorus slag show that the slag contains nine nonradioactive contaminants in concentrations that exceed the risk screening criteria, although only four constituents exceed the criteria by more than a factor of 10. In addition, the slag contains elevated concentrations of uranium-238 and its decay products that may pose a significant radiation hazard if the slag is not properly controlled. Based on available sampling data and professional judgment, however, EPA does not believe that the slag exhibits any of the characteristics of hazardous waste (ignitability, corrosivity, reactivity, or EP toxicity).

Elemental phosphorus slag has been widely used for many years for a variety of purposes, many of which can cause increased radiation exposure to people living or working near the slag-bearing materials. Recently completed EPA research shows that significant cancer risks have been caused by the off-site use of elemental phosphorus slag in street paving and home foundations in Soda Springs and Pocatello, ID. According to these research findings, average lifetime cancer risks caused by exposures to direct gamma radiation from these materials range from $4x10^{-4}$ in Pocatello to $1x10^{-3}$ in Soda Springs; lifetime cancer risks of maximally exposed individuals in these two cities can be as high as $6x10^{-3}$. EPA notes, however, that the cancer risks in these two cities may actually be a factor of two higher. Because of these high risks, the State of Idaho banned the use of elemental phosphorus slag in all occupied structures in 1977, but slag can still be used as an aggregate in road construction in Idaho. Any future uses of elemental phosphorus slag in Idaho and elsewhere need to be closely evaluated and controlled to prevent high radiation exposures.

Based on a review of existing management practices and release/exposure conditions, EPA believes that the current practices of managing the slag at the five active elemental phosphorus facilities generally pose a low risk via the ground-water and surface water exposure pathways. Although low levels of ground-water recharge and large depths to ground water at three of the facilities appear to limit the potential for slag contaminants to migrate into ground water, contamination that may be attributable to the slag has been observed. At the other two facilities, releases of constituents are not controlled by favorable hydrogeologic conditions, so migration of contaminants into ground water is possible. This migration, however, is not expected to pose significant current risks at any of the sites because of the relatively low concentrations of potentially harmful constituents in laboratory leachate of the slag. The generally large size of slag particles limits the potential for water erosion to transport slag contaminants to surface water exposure points. Surface water contamination potential is also limited by the relatively large distances from three of the facilities to the nearest surface waters. The absence of documented cases of ground-water and surface water damage that clearly results from elemental phosphorus slag management further supports the finding that this waste, when managed on-site, poses a relatively low ground-water and surface water risk.

However, EPA believes that current slag management at three facilities poses a moderate risk via the air exposure pathway. Although the generally large size of slag particles tends to limit wind erosion, large quantities of dust blowing from the slag pile at one facility has been alleged by nearby residents and the slag pile at another facility is recognized as a potential contributor to high levels of airborne particulates. Exposures of nearby residents to any windblown contaminants at these two and one other facility are possible, and EPA acknowledges the need for further study and possible control of windblown dust at these sites. Air pathway exposures at the other two facilities are, at present, less likely because of the large distance to potential receptors.

7.4 Existing Federal and State Waste Management Controls

7.4.1 Federal Regulation

The Stauffer Chemical Company facility in Silver Bow, Montana, which generates elemental phosphorus slag, is located on Federal land (in a National forest), and is therefore subject to the regulations set forth by the U.S. Department of Agriculture's Forest Service. The regulations governing the use of the surface of National Forest Service lands (36 CFR 228 Subpart A) are intended to "minimize adverse environmental impacts...." They require that operators file a "notice of intent to operate." If deemed necessary, the operator may be required to submit a proposed plan of operations in order to ensure minimal adverse environmental impact.

Section 3001(b)(3)(iii) of RCRA, which was added by the Solid Waste Disposal Act Amendments of 1980 (Oct. 21, 1980), provides EPA with the authority to develop regulations "to prevent radiation exposure which presents an unreasonable risk to human health from the use in construction or land reclamation (with or without revegetation) of (I) solid waste from the extraction, beneficiation, and processing of phosphate rock or (II) overburden from the mining of uranium ore."

The National Environmental Policy Act (NEPA) may also be applicable to this facility. NEPA may require that an Environmental Impact Statement (EIS), which establishes the framework by which EPA and the Council on Environmental Quality may impose environmental protection requirements (40 CFR Parts 1500-1508), be prepared for any ore processing activities on Federal lands.

EPA is unaware of any other specific management control or pollutant release requirements that apply specifically to elemental phosphorus slag (the October, 1989 National Emissions Standard for Hazardous Air Pollutants (NESHAP) controlling radionuclide emissions from elemental phosphorus plants only addresses stack emissions, not slag or other potential radionuclide sources (54 FR 51671)).

In the State of Idaho, which has no EPA-approved NPDES program, EPA would utilize State water quality standards when writing NPDES permits.

7.4.2 State Regulation

The five facilities generating elemental phosphorus furnace slag are located in three states, Idaho, Tennessee, and Montana. Two facilities are located in both Idaho and Tennessee, while a single facility is located in Montana. All three states were selected for regulatory review for the purposes of this report (see Chapter 2 for a discussion of the methodology used to select states for detailed regulatory study).

All three states with elemental phosphorus facilities exclude mineral processing wastes, including the furnace slag generated at these facilities, from hazardous waste regulation. Of the three states, only Tennessee has solid waste regulatory provisions that apply to elemental phosphorus furnace slag. Tennessee's solid waste regulations include provisions for industrial solid waste landfills, which include landfills used to dispose of furnace slag. The state's implementation of its solid waste regulations, however, has focused on municipal solid waste landfills; the two elemental phosphorus facilities in Tennessee both have permits for on-site industrial landfills, but are not currently subject to strict design or operating criteria. Tennessee recently amended its regulations and appears to be preparing to regulate mineral processing wastes more comprehensively. Under the new regulations, the two elemental phosphorus facilities could be required to undertake various management practices, such as the submission of design drawings for approval, the preparation of contouring plans, the installation of liners and leachate collection systems, and conditional ground-water monitoring. The new regulations also include provisions for financial assurance for closure and 30 years of post-closure care.

In contrast to Tennessee's solid waste regulatory efforts, neither Idaho nor Montana currently regulates elemental phosphorus slag as solid waste. Idaho does not require solid waste permits for the disposal of mineral processing wastes, including elemental phosphorus furnace slag. Montana classifies mineral processing wastes as solid wastes, but does not regulate these wastes if they are disposed of on-site, as happens at the single Montana elemental phosphorus facility, and the wastes do not pose a nuisance or health hazard. Of all three states, only Idaho specifically prohibits the use of elemental phosphorus furnace slag in construction materials for habitable structures.

Water and air quality regulations vary in their applicability to mineral processing wastes across the three states, but generally follow the pattern set by current solid waste regulation. Tennessee's water quality regulations require that no sewage, industrial waste, or other wastes may cause a violation of state water quality standards. Both facilities in Tennessee maintain state-administered NPDES permits. Idaho's regulations make no mention specifically of mineral processing wastes but require all non-sewage discharges to be treated in order to comply with federal water quality standards. According to state officials in Montana, run-off from elemental phosphorus slag piles does not require a NPDES permit and is not addressed otherwise. Finally, although mineral processing facilities in all three states must obtain air permits in order to operate, there are no specific regulations addressing fugitive dust suppression for elemental phosphorus furnace slag in any of the three states.

In summary, all three states with elemental phosphorus facilities exclude from hazardous waste regulation the furnace slag generated at those facilities. Moreover, two of the states, Idaho and Montana, are effectively not requiring environmental controls for on-site disposal of these slags under their solid waste regulations. Tennessee's solid waste regulations do include provisions for industrial solid wastes. Although these regulations have not been implemented aggressively to date, the state recently revised its solid waste rules and appears to be preparing to regulate furnace slag and other mineral processing wastes more comprehensively. Tennessee and Idaho have water quality provisions that could apply to furnace slag waste management activities, though only the two facilities in Tennessee maintain NPDES permits for those activities. Montana does not require a NPDES permit for run-off discharges from its facility's furnace slag waste piles. Finally, none of the three states have fugitive dust suppression provisions for furnace slag disposal units in their air regulations.

7.5 Waste Management Alternatives and Potential Utilization

Waste Management Alternatives

By waste management alternatives, EPA is referring to both ways of actually disposing of the waste (e.g., landfills and waste piles), and methods of minimizing the amount of waste generated. Waste minimization generally encompasses any source reduction or recycling that results in either the reduction of total volume or toxicity of hazardous waste. Source reduction is a reduction of waste generation at the source, usually within a process. Source reduction can include process modifications, feedstock (raw material) substitution, housekeeping and management practices, and increases in efficiency of machinery and equipment. Source reduction includes any activity that reduces the amount of waste that exits a process. Recycling refers to the use or reuse of a waste as an effective substitute for a commercial product, or as an ingredient or feedstock in an industrial process.

Disposal Alternatives

Of the four facilities that did not designate the relevant portions of their 1989 SWMPF Surveys as confidential, none sends its slag off-site for disposal. While it is conceivable that some, or even all, of the facilities could do so, the cost of transporting large volumes of phosphorus slag, and the rising cost of commercial landfill capacity make it unlikely that elemental phosphorus processors will utilize off-site disposal capacity if on-site capacity is available and the regulatory status of the material does not change. Situations that could increase the likelihood of off-site disposal are the classification of elemental phosphorus slag as hazardous waste, a limited amount of area for on-site disposal, and reduced slag generation rates. Increased need for disposal in general (either on-site or off-site) would result from increased restrictions on uses of the slag.

Waste Minimization

Opportunities for waste minimization may include raw material substitutions, though these opportunities are somewhat limited because of the transportation costs involved in using ores or concentrates produced in other regions or countries. Consequently, raw materials substitution generally takes the form of improving the separation of the value from the raw ore during beneficiation, so that the furnace operations would begin with a higher grade of ore concentrate. Processing a feedstock with a higher concentration of phosphorus results in decreased slag generation, although presumably increasing the generation of related beneficiation wastes. Other source reduction opportunities may involve processing modifications to increase the efficiency of phosphorus recovery during the furnace operation.

Waste Utilization

Utilization of mineral processing "wastes" can be a viable alternative to disposal. In 1988, for example, Occidental's Columbia plant reported selling all of its slag, while three other facilities are known to have sold some portion of their slag for off-site use (specific data are confidential). Only the Silver Bow facility reported disposing all of its slag rather than selling it as a product. However, there may be risks associated with such practices, as indicated by the EPA studies in Idaho.

Option 1: Utilization as a Highway Construction Aggregate

Description. Phosphorus slag is used as an aggregate in asphalt manufacturing. It normally requires crushing and sizing by slag processing contractors to meet specific aggregate size requirements before it can be mixed with the asphalt.

Current and Potential Use. Elemental phosphorus slag has been used extensively in highway construction for many years in Idaho, Montana, and Tennessee.[20] Its hardness, uniformity, and inert chemical composition make it an excellent aggregate material for construction purposes and it is specified as a skid resistant coarse aggregate in bituminous wearing surfaces. The material is used in various phases of highway construction, including crushed base, crushed aggregate for asphalt (i.e., bituminous paving and seal coats), and as casting material for highway structures. The Occidental facility in Tennessee was able to sell nearly all of the slag it produced in 1988, a significant portion of which is believed to have been used for highway construction.[21] The facility indicated that they could sell even more of the material if more was produced. The demand for phosphorus slag is high in Tennessee because supplies of natural aggregate are sparse. As noted above, however, recent studies in Idaho indicate that such uses contribute significantly to gamma radiation exposure of the local populations.

Although the Stauffer Chemical Company in Montana reportedly sold none of the slag that it generated in 1988, phosphorus slag is known to have widespread usage in road construction in both Idaho and Montana.[22] Demand for the slag as an aggregate in Idaho and Montana is expected to be lower than the demand in Tennessee because of the locations of the facilities with respect to market areas and the problem of residual radioactivity in the western ores.

The potential of phosphorus slag as a construction aggregate depends, at least partly, on its ability to successfully compete in the market place with the other sources of aggregates. The effect of facility location on its competitiveness in the market is discussed below, and competitive pricing is discussed in the section on feasibility.

Access to Markets. Because aggregate is a relatively low value, high bulk commodity, transportation costs are a key factor in establishing and maintaining markets for this product. Accordingly, producers must be located in

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[20] Collins, R.J. and R.H. Miller, Availability of Mining Wastes and Their Potential for Use as Highway Material - Volume I: Classification and Technical and Environmental Analysis, FHWA-RD-76-106, prepared for Federal Highway Administration, May 1976, p. 168.

[21] Private communication with Eddie Floyd, Occidental Chemical Co., April 11, 1990.

[22] Collins, R.J. and R.H. Miller, op.cit.

relatively close proximity to product markets to be price competitive and, therefore, economically viable, or aggregate must be in short supply to justify haul distances greater than 80 to 160 km (50 to 100 miles).[23] The two facilities in Idaho are both located approximately 480 km from Salt Lake City, 320 km from Twin Falls, and less than 400 km from Pocatello. The two facilities are also located within 400 km of an area in central Montana that has an aggregate shortage. The Stauffer plant in Silver Bow, Montana is located within 16 km of Butte, within 160 km of Helena and Missoula, and less than 240 km from the area in central Montana with an aggregate shortage. The two facilities in Tennessee are both located within 160 km of Nashville, Huntsville, and Chattanooga, and within 160 km of an area in eastern Tennessee with an aggregate shortage. The Tennessee facilities are also located approximately 480 km from Memphis and an aggregate shortage area in western Tennessee. Therefore, all of the facilities have potential markets for their slag as an aggregate material.

Factors Relevant to Regulatory Status. The primary environmental concern for elemental phosphorus slag stems from the radionuclides found in the slag. The slag is typically composed of approximately 44 percent calcium, or lime (CaO), 44 percent silica (SiO_2), 6 percent alumina (Al_2O_3), 1 percent iron oxide (Fe_2O_3); it also contains most of the nonvolatile radionuclides originally present in the ore. Radium-226 levels in elemental phosphorus slags from Idaho and Montana have been observed to range from 4 to 32 pCi/g, whereas the concentrations in slag from the two facilities in Tennessee have been measured at 3.2 to 27 pCi/g.[24,25] Concentrations of uranium and thorium in elemental phosphorus slag range from 23 to 50 pCi/g in Montana and Idaho, and from 2.4 to 45 pCi/g in Tennessee.[26,27]

Due to concerns over radiation exposure, the State of Idaho has prohibited the use of phosphorus slag in the construction of habitable structures since 1977,[28] though slag is still used as an aggregate in road construction in Idaho. Exposure rates of 100 microroentgens per hour (µR/h) have been measured at outdoor slag piles at the FMC plant in Pocatello, Idaho,[29] as compared to natural background radiation in the same area of 9 µR/h.[30] In addition, significant gamma radiation exposures associated with a variety of slag construction uses have been identified (see discussion in Section 7.3.1).

While there are a number of constituents that can leach from elemental phosphorus slag, the entrainment of the slag within the asphalt matrix should significantly reduce the potential for leaching. In addition, the slag itself is a glass-like material containing the radionuclides in a vitrified matrix, which significantly limits leaching potential in the original material. However, if the asphalt were to exhibit any undesirable characteristics (e.g., significant leaching of radionuclides), the environmental impacts could be extensive because the slag would be widely distributed.

The slag particles that are too small to be used as aggregate require disposal, unless they can be utilized in some other way (e.g., as a substitute for portland cement, as is discussed later). If disposed, there is a greater potential for leaching, since the small particle size of the slag fines will cause them to have a greater surface area than the same quantity of unprocessed phosphorus slag.

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[23] Ibid, p. 239.

[24] Stula, R.T., et. al., Airborne Emission Control Technology for the Elemental Phosphorus Industry--Final Report to the Environmental Protection Agency, prepared for U.S. Environmental Protection Agency Under Contract Number 68-01-6429, January 26, 1984, pp. 3-38, 3-59, 3-75, 3-129, and 3-162. Data provided in this report for facilities that have been closed are not included in the discussion here.

[25] Company responses to EPA's National Survey; see footnote 2.

[26] Stula, et. al., op. cit., pp. 3-38, 3-59, 3-76, 3-129, and 3-162.

[27] Company responses to EPA's National Survey; see footnote 2.

[28] Baker, E.G., H.D. Freeman, and J.N. Hartley, Idaho Radionuclide Exposure Study--Literature Review, prepared for U.S. Environmental Protection Agency, Office of Radiation Programs, under a related services contract with the U.S. Department of Energy, Contract DE-AC06-76RLO 1830, October, 1987, p. 4,6

[29] Radiological Surveys of Idaho Phosphate Ore Processing - The Thermal Process Plant, prepared for the U.S. Environmental Protection Agency, Office of Radiation, Los Vegas Facility, November, 1977, pp. 8-9.

[30] Ibid.

Feasibility. The use of elemental phosphorus slag in highway construction is technically and economically feasible, as evidenced by its continued use for this purpose. EPA has not identified any existing regulatory constraints on the use of phosphorus slag in highway construction.

Future slag utilization as an aggregate will depend on the price of competing aggregate materials, the cost of retrieving and crushing and screening (i.e., sizing) the slag, the distance the slag must be transported to its point of use, regulatory limitations, and its social acceptability (i.e., concerns over radiation risks).

Other Options

There are a number of other potential ways to utilize phosphorus slag which are mentioned in the literature, but for which there is little information beyond the fact that an alternative use of the slag has been employed. In the following paragraphs, EPA discusses and comments on each alternative to the extent permitted by the available information.

Use in Making Portland Cement and Concrete. Phosphorus slag has been used as a substitute for portland cement rock in the manufacturing of portland cement.[31] In addition, the University of Tennessee has evaluated several sources of phosphorus slag for use as fine aggregates. As a result of this study, phosphorus slag produced by Monsanto at Columbia, Tennessee, were found to be acceptable (in terms of materials performance) for use in portland cement concrete.[32] The slag has been used as an aggregate for portland cement concrete in making constructions blocks, and pouring driveways, patios, and drainage ditches.[33] However, such uses have been prohibited in some areas and significant gamma radiation exposure from such uses has been documented (see Section 7.3.1).

Radionuclide emission testing of the use of phosphorus slag as a construction aggregate led to a 1977 ban by the State of Idaho on the use of the material in construction of habitable structures.[34] However, the radionuclide properties of phosphorus slag vary significantly by the location of the ore deposits. Therefore, the feasibility and acceptability of using phosphorus slag as an aggregate for portland cement concrete will also depend on the origin of the slag.

Raw Material for Making Ceramic Tile. Phosphorus slag was found to have a composition corresponding to a pseudo-wollastonite known as the alpha form of natural wollastonite, a mineral that is mined in large tonnages to supply the ceramic tile industry. Research has demonstrated that phosphorus slag would be suitable (in terms of materials performance) for use in production of high-quality tile products. When properly ground and treated magnetically to remove iron constituents (magnetite), the slag comprised a raw material suitable for forming, dry pressing, sintering, and glazing to yield high quality floor and wall tile. The estimated production cost compared favorably with the cost of commercially produced wall tile.

Railroad Ballast and General Construction Uses. Elemental phosphorus slag is currently used as railroad ballast and as stabilization material for stockyards.[35] In Florida, where the use of elemental phosphorus slag in

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[31] Kirk Othmer, Encyclopedia of Chemical Technology, Third Edition, Volume 5, Wiley-Interscience Publications, John Wiley and Sons, p. 187.

[32] Collins, R.J. and R.H. Miller, op.cit., p. 197.

[33] Stula, et. al., op. cit., pp. 3-4.

[34] Baker, Freeman, and Hartley, op. cit.

[35] Baker, Freeman, and Hartley, op.cit., pp. 4-6.

habitable structures has not been prohibited, slag has been used on roofing shingles and in septic tank fields. It has also been used in the manufacturing of rockwool insulation.[36]

Using phosphorus slag as railroad ballast or in general construction use does not change the chemical or physical characteristics of the slag, although it may have some effect on the ability of the slag's potentially hazardous constituents to leach and contaminate ground and/or surface waters. The concentration of radium-226 in slag pile rainwater runoff at the Pocatello plant has been observed to be 0.70 pCi/g in the liquid fraction and 14 pCi/L in the suspended solids fraction. When the slag is used as railroad ballast, the surface area available for leaching may be increased, though the actual rate of leaching will depend on environmental settings, and could therefore vary considerably.

7.6 Cost and Economic Impacts

Because the available data indicated that elemental phosphorus slag does not exhibit any of the characteristics of hazardous waste, the issue of how waste management costs might change if Subtitle C regulatory requirements were applied and what impacts such costs might impose upon affected facilities is moot. Accordingly, EPA has not estimated costs associated with removing elemental phosphorus slag from the Mining Waste Exclusion, which EPA's data indicate would have no practical effect on waste management costs.

EPA does have significant concerns about certain off-site uses of elemental phosphorus slag because of the relatively high residual radioactivity contained within this material. EPA has not, however, calculated the costs or impacts associated with limiting or prohibiting sales of elemental phosphorus slag for particular off-site uses for this report.

7.7 Summary

As discussed in Chapter 2, EPA developed a step-wise process for considering the information collected in response to the RCRA §8002(p) study factors. This process has enabled the Agency to condense the information presented in the previous six sections of this chapter into three basic categories. For the special waste generated by this commodity sector (elemental phosphorus slag), these categories address the following three major topics: (1) the potential for and documented danger to human health and the environment; (2) the need for and desirability of additional regulation; and (3) the costs and impacts of potential Subtitle C regulation.

Potential and Documented Danger to Human Health and the Environment

The intrinsic hazard of elemental phosphorus slag is moderate to high in comparison to the other mineral processing wastes studied in this report. The slag does not exhibit any of the four characteristics of hazardous waste and contains only four constituents that exceed one or more of the screening criteria used in this analysis by more than a factor 10. However, elemental phosphorus slag also contains elevated concentrations of uranium-238 and its decay products that may pose a significant radiation hazard if the slag is not properly controlled.

Based on a review of existing management practices and release/exposure conditions, EPA believes that the current <u>on-site</u> slag management practices at the five active elemental phosphorus facilities generally pose a low risk via the ground-water and surface water exposure pathways. Low levels of ground-water recharge and large depths to ground water at three of the facilities appear to limit the potential for slag to cause ground-water contamination, but contamination that may be attributable to the slag has been observed. At the other two facilities, releases of constituents are not controlled by favorable hydrogeologic conditions, so migration of contaminants into ground water is possible. This migration, however, is not expected to pose significant risks at any of the sites because of the relatively low concentrations of potentially harmful constituents in slag leachate, as determined by laboratory tests. The generally large size of slag particles limits the potential for stormwater erosion to transport slag contaminants to surface water

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[36] Stula, et. al., op.cit., pp. 3-4.

exposure points. Surface water contamination potential is also limited by the relatively large distances from three of the facilities to the nearest surface waters. The absence of documented cases of ground-water and surface water damage that clearly results from elemental phosphorus slag disposal further supports the finding that on-site disposal of this waste poses a relatively low risk via these pathways. However, EPA believes that on-site slag management at three facilities poses a moderate risk via the air exposure pathway. Although the generally large size of slag particles also tends to limit wind erosion, dust from the slag piles may be blown into the air and lead to significant exposures of residents near three of the plants. No people live near the other two plants and significant exposures through the air pathway are not likely at these plants.

In contrast, EPA studies have shown that use of elemental phosphorus slag in residential building and municipal (e.g., road, sidewalk) construction applications has resulted in unacceptable human exposure to gamma radiation and resultant high incremental cancer risk. According to recent EPA research findings, average lifetime cancer risks caused by exposures to direct gamma radiation from elemental phosphorus slag used in street paving and home foundations in Soda Springs and Pocatello, ID range from $4x10^{-4}$ to $1x10^{-3}$; lifetime cancer risks of maximally exposed individuals in the two cities that were studied can be as high as $6x10^{-3}$.[37] EPA notes with interest that use of slag in inhabited structures has been prohibited in the State of Idaho for more than ten years, and believes that the radiation risks associated with the off-site use of elemental phosphorus slag should also be addressed on the national level.

Likelihood That Existing Risks/Impacts Will Continue in the Absence of Subtitle C Regulation

The relatively low to moderate risk from the on-site management of elemental phosphorus slag is expected to continue in the future in the absence of Subtitle C regulation given current waste management practices and environmental conditions at the five active facilities. The characteristics of this waste are unlikely to change in the future, and although this analysis is limited to the five sites at which the waste is currently managed, EPA believes that it is unlikely, based on overall market conditions and the marginal profitability of the industry, that elemental phosphorus production will expand to other locations. Therefore, the Agency believes that the findings and conclusions of this study reflect conditions at all locations at which elemental phosphorus slag is expected to be managed on-site in the future.

In the absence of more stringent federal regulation of on-site management of elemental phosphorus slag, state regulation is expected to continue to control risks to a limited extent. Furnace slag from elemental phosphorus production is generated in three states, Tennessee, Montana, and Idaho, all of which exempt this waste from hazardous waste regulation. Of these three states, only Tennessee addresses furnace slag under its solid waste regulations. Tennessee, however, has historically focused its regulatory efforts on municipal solid waste problems; the two elemental phosphorus facilities in the state both have permits for on-site industrial landfills, but are not currently subject to strict design or operating criteria. Tennessee recently revised its regulations to address industrial solid wastes, including mineral processing wastes such as furnace slag, more stringently. Montana exempts furnace slag from its solid waste regulations if it is disposed on-site, as happens at the single Montana elemental phosphorus facility. Idaho's solid waste regulations do not address any mineral processing wastes, though the state does ban the use of elemental phosphorus furnace slag in construction materials for habitable structures. Only Tennessee appears to actively regulate surface water discharges from furnace slag piles, while none of the states specifically apply fugitive dust control requirements to these wastes.

Costs and Impacts of Subtitle C Regulation

Because of the low risk potential of on-site management of elemental phosphorus slag, the absence of documented damages caused by on-site disposal of this material, and the fact that this waste does not exhibit any

[37] Recent revisions of risk factors for radiation exposure indicate that actual risks may even be a factor of two higher than those stated here.

characteristics of hazardous waste, EPA has not estimated the costs and associated impacts of regulating elemental phosphorus slag under RCRA Subtitle C.